

CONTRIBUTION OF A LINEAR PROGRAMMING VBA MODULE TO STUDENTS PEFORMANCE

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Abstract

This paper deals with the application of freeware modules as a teaching support of Operations Research methods at the Department of Systems Engineering, Czech university of Life Sciences (CULS) Prague. In particular, we concentrated on a linear programming module and measured the impact on student performance. The motivation for this evaluation is based on a current development of a new module that focuses on Traveling Salesman Problem. First, we explain the current situation both worldwide and in the Czech Republic and the CULS Prague. Subsequently, we describe the content of students' exams and statistical methods applied to the evaluation. Finally, we analyze and generalize the obtained results. The students exams have show a positive impact of the modules. Further, our analysis has proven that this impact is statistically significant. The findings motivate us to made new modules for other methods.

Key Words

Education, Linear programming, Traveling Salesman Problem, Paired t-Test, McNemar Test, Pearson Contingency Coefficient, Item Analysis

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Introduction

Throughout the recent years, the members of the Department of Systems Engineering (DSE), Faculty of Economics and Management (FEM), Czech University of Life Sciences (CULS), have developed freeware software for many methods from different branches of the operations research. The majority of these software packages focuses on linear programming, multi criteria analysis, transportation problems and structural analysis (i.e. input output tables) but more of core problems and algorithms of Operations Research have been already compiled into simple computer free programs.

On the market, there is relatively a lot of professional software focusing on such problems and algorithms as What'sBest, LINGO, LINDO, Optimization Toolbox for MATLAB or free Scilab and its optimization and statistical ATOMS etc. Their accessibility and further copying to private student's PCs are often restricted by authors' rights and license cost, which usually exceeds students' possibilities. Another common disadvantage of such software packages is specific user interface that is new for a non-experienced user. The target group of the modules developed at the DSE consists, in the first place, of students in the first or second year of study at the Faculty of Economics and Management, CULS Prague. The main purpose of the modules is just the support of teaching and learning of elementary algorithms in basic courses, not any special software training. Therefore, all the modules are programmed in Visual Basic for Applications (VBA) and use well known user interface of MS Excel.

At universities and other types of schools all over the world, similar VBA modules are often used in the teaching of operations research. This issue is dealt with in a complex way in (Martin 2000). These modules are used most often to discrete event

simulations of queues (De Mesquita and Hernandez 2006), (Elizandro and Matson 2005), (Grossman Jr. 1999). An application of VBA modules in the games theory teaching (Nassar 2002) is also interesting. However, we concern in this article particularly with the teaching of linear programming (especially the simplex method) and the Travelling Salesman Problem. We did not succeed in finding any example of using VBA modules in the teaching of these topics. For instance at the University of North Carolina, MATLAB is used for the teaching of the Traveling Salesman Problem and other integer programming tasks (Pataki 2003). On the contrary, VBA modules for linear programming are usually created for the purpose of solving large tasks from practice (LeBlanc and Galbreth 2007).

The situation is also similar at Czech universities. For instance, at the University of Economics there were created VBA modules in MS Excel for the teaching of multiple-criteria decision making (Benešová, Skočdoplová and Kuncová 2010). For linear programming teaching a very thoroughly worked-out teaching system is used at the same university, however, based on the utilisation of MS Access (Lagová and Kalčevová 2006), (Lagová and Kalčevová 2007), (Lagová and Kalčevová 2008). An interesting action was taken at Mendel University in Brno where a module for the critical path method teaching was created using the programme of Macromedia Flash 8 (Zach, Holoubek and Kolman 2010).

All of the above mentioned papers concerning the VBA modules and other software application in teaching mention its impact on the teaching quality. However, we have not managed to find a paper quantifying the impact on student performance as we do below.

Current effort at the DSE is to develop a new module that focuses on the Travelling Salesman Problem. This problem is

commonly taught in different courses of mathematical methods in economics and management. It is also a popular topic of practically oriented bachelor and diploma theses. That is why we assume that this module is missing and its development and further availability would be worthy.

But such assumption can be wrong and, if non-verified, it is not a sufficiently strong reason for software development and especially for its implementation into courses. This is the main aim of this paper – to evaluate the educational impact of already existing and the most used of the software modules LINKOSA – a module for linear programming. The students sat for the same type of the exam on linear model results analysis twice, the first without and the second with the possibility of using the LINKOSA module. We compared achieved results in both cases. We believe that such evaluation can be generalized to other modules and a positive result presents the reason for further development of another module.

In this paper we extend and deepen results observed in (Kučera, Krejčí, Vydrová and Kučirková 2010).

Material and Methods

LINKOSA Module Description

This module provides linear programming model solutions. The input is the model with constraints in the inequality form (slack variables will be added by the module itself). The outputs are arranged into four sheets. The first one contains an optimum solution. It consists of two tables: the first one with the list of optimum values of decision variables, and the second one comprising the values of the right-hand sides and reserves/exceedings for every constraint in the optimum solution (i.e. optimum values of the slack variables). In the second sheet there

is a complete final simplex table in a revised form (i.e. without the columns of basic variables) which is a valuable source for postoptimalization considerations and analyses. The remaining two sheets comprise the survey of base stability intervals (even if they can be determined from a final simplex table), one for right-hand sides and the second for costs. These intervals set the range in which a given parameter can move without changing the optimum base. For more information about the simplex method and its interesting applications see e.g. (Hall and McKinnon 2004), (Tehrani Nejad Moghaddam and Michelot 2009).

Exam for Evaluating the LINKOSA Module Impact

The exam for students that should have shown how LINKOSA is contributonal consisted in the following example. An agricultural enterprise should have grown three crops (decision variables x_1, x_2, x_3 express the areas on which they are grown) and there were set the following constraints: disposable area of arable land b_1 in hectares, an upper limitation b_2 of the area for one of the crops (let us denote the corresponding decision variable x_1) also in hectares and a minimum required value b_3 of sales in thousands of Czech crowns. The aim was to maximize the profit z , expressed in hundreds of Czech crowns. The linear model was of the following form:

$$\begin{aligned}x_1 + x_2 + x_3 &\leq b_1 \\x_1 &\leq b_2 \\a_{31}x_1 + a_{32}x_2 + a_{33}x_3 &\geq b_3 \\x_1 \geq 0; x_2 \geq 0; x_3 &\geq 0 \\z = c_1x_1 + c_2x_2 + c_3x_3 &\rightarrow \max\end{aligned}$$

where a_{31} , a_{32} , a_{33} and c_1 , c_2 , c_3 are the sales from 1 ha in thousands of Czech crowns and the profit from 1 ha in hundreds of Czech crowns for single crops, respectively.

The example was prepared in several numerically mutually different variants. Disposable area b_1 moved in the range from 450 to 1200 ha in single variants and the values were divisible by 50. The upper limitations b_2 were three-digit values again divisible by 50. Required sales b_3 were four-digit values divisible by 100 (from the matter-of-fact view, owing to the fact that they were stated in thousands of Czech crowns, it concerned the millions of Czech crowns). Coefficients a_{31} , a_{32} , a_{33} were one-digit integers and coefficients c_1 , c_2 , c_3 were at most two-digit integers. In the final simplex table all the values were always integers. Correct answers in every variant of the exam (see below) were either integer values or fractions, but in the worst case thirds. In this way the same numerical difficulty of the calculation of all the variants was ensured in a sufficient degree.

The instruction given to students comprised a brief verbal description and an initial and final table of the model. The form of the initial and final simplex table is shown on an example in table 1.

		53	5	25	0	0	0	-100	
		x_1	x_2	x_3	x_4	x_5	x_6	x_7	
0	x_4	1	1	1	1	0	0	0	450
0	x_5	1	0	0	0	1	0	0	100
-100	x_7	6	1	3	0	0	-1	1	1300
$z_j - c_j$		-653	-105	-325	0	0	100	0	-130000

0	x_6	0	2	0	3	3	1	-1	350
53	x_1	1	0	0	0	1	0	0	100
25	x_3	0	1	1	1	-1	0	0	350
$z_j - c_j$		0	20	0	25	28	0	100	14050

Table 1: Example of the initial and final table in the exam

Every exam variant consisted of six numeric items that should be fulfilled by the students:

- How much the amount of sales will change in the optimum solution when decreasing arable land (the change of an optimum variable value when changing the value of the right-hand side).
- How much the profit will change in the optimum solution with the same decrease of arable land as in the previous question (the change of an optimum value of the objective function when changing the value of the right-hand side).
- What is the minimum area of arable land for achieving required sales (the limit of the stability interval of the right-hand side).
- On what areas single crops will be grown if there is an increase in the profit with the crop that is not worth growing so that it would be worth growing (entering of non-base variable into the base), i. e. three items.

Statistical Testing

For assessing the difference between the exam solution with or without the usage of SW module, the testing of statistical hypotheses was used. A statistical hypothesis is a certain presupposition about the characteristics of the distribution of an examined random variable. The testing of a given hypothesis

is the procedure by which we make decision about the validity or refusal of a null hypothesis on the basis of random choices.

Owing to the character of input data we chose the paired t-test. It is used in the case of two dependent samples from a two-dimensional normal random variable (X, Y). It evaluates a conclusive non-nullity of a mean difference between pair measurements of values. We want to find out whether a given trial had any influence on a measured object.

A standard error necessary for the calculation of testing statistics is calculated according to the formula:

$$s_{\bar{d}} = \frac{1}{\sqrt{n}} \sqrt{\frac{\sum_i (d_i - \bar{d})^2}{n-1}} \quad (1.1)$$

where the difference $d_i = x_i - y_i$ and n is a number of pairs.

We usually test a null hypothesis $H_0: \mu_d = 0$. In this case the testing statistics is in the following form:

$$t = \frac{\bar{d}}{s_{\bar{d}}} \quad (1.2)$$

For more details, advantages and disadvantages, see (Zimmerman 1997).

The strength of the exam results dependence can be found out using a two-dimensional table made by the classification of two dependent variables – the results of the first exam and the results of the second exam. The basic test for finding out the dependence of two dependent samples is the McNemar test on mutual (in)dependence in a contingency table (McNemar 1947).

Denoting the table $\begin{pmatrix} a & b \\ c & d \end{pmatrix}$, we are testing whether the numbers b and c differ from each other only within the framework of

random fluctuating. We compare the test statistics χ^2 with a critical value of χ^2 distribution with the degrees of freedom $[(r-1)(s-1)]$, where r and s are the numbers of the contingency table rows and columns, respectively. The formula for testing statistic χ^2 is

$$\chi^2 = \frac{(b-c)^2}{b+c} \quad (1.3)$$

For measuring the dependence strength, i. e. relation among the variables, we can use several coefficients functioning similarly as a correlation coefficient. We can use Pearson contingency coefficient (C_p) (Hendl 2004), which takes values from the

interval $\langle 0; \sqrt{(q-1)/q} \rangle$, where $q = \min \{r, s\}$. For C_p calculation we use the following relation.

$$C_p = \sqrt{\frac{c_p^2}{c_p^2 + n}} \quad (1.4)$$

The item analysis is used for exploring the characteristics of single items of the exam. It is suitable for judging the quality of each of its questions. It involves two types of analysis: quantitative (e.g. correlation, burdensomeness, time demand) and qualitative (lucidity, content and format adequacy, etc.). The item is the smallest unit of the exam according to which it is possible to judge a given exam using the item analysis.

In this analysis the following statistical parameters are used in accordance with the classical exam theory.

The facility indicates how easy the question is for a student. In the case of the dichotomic form of the question (correct/wrong answer) this parameter is equal to proportional (or percentage) expression of the correct answers of students. This parameter

can be clearly described by the formula $ease = \frac{X_{mean}}{X_{max}}$, where X_{mean} is the average number of points obtained by all the students for a given item and X_{max} is the maximum possible number of points.

The discrimination index (DI) shows how much (to what degree) an item makes a difference between successful and unsuccessful students. With this index it is possible to compare the result of e.g. this item, or the whole exam, and the results of all the other items, or other exams, respectively. In general, we can state that a student with good results will write the exam well, and, on the contrary, a bad student will not succeed. The discrimination index is a rough indicator of the efficiency of each item in a given students' group.

For determining the value of this index, we take one third of all the students with the best results and one third of students with the worst results, and then we find out how these groups of students have solved a given question. In the ideal case the best students should succeed and the worst ones should fail. For each of these two groups we compute the mean value of the proportional expressions of the results of all its members and subtract the mean value of the latter group from the mean value of the former group.

The value of this index ranges in the interval from -1 to +1. Negative values show that the correct answer has been given more often by worse students than by the best students at the corresponding questions.

The discrimination coefficient (DC), from the statistical point of view, is a correlation coefficient between the score for a given item and for the whole exam. It shows how much (to what extent) the results would be different if we differed between clever and

less clever students. As in the case of the DI, this index takes values from -1 to +1. Positive values show the difference of the clever students. Negative values indicate items which have been answered wrong by the best students.

The advantage of the DC is that it uses the data of all the results for computing, and not only the results of one third of the best and the worst students as in the case of the DI.

For more information about the item analysis and some of its interesting applications see e.g. (De Champlain 2010) or (Lonn and Teasley 2009).

All statistical calculations we carried out using the STATISTICA 8 software, except for some calculations of the item analysis which we carried out directly in MS-Excel.

Results and Discussion

In the analysed sample with 197 students of the Economics and Management, and Business and Administration fields of study we found out and evaluated the differences between the results of two exams (every student wrote the exam twice, every time a different variant) within the course of Economic and mathematical methods I. For the first time the students wrote the exam before they got acquainted with the LINKOSA module. So they could use only their own knowledge of a particular computation procedure and a scientific calculator. For the second time they knew LINKOSA programme and could use it for the calculation and the analysis of a given problem. In both cases they were given the time limit of 15 minutes for solving the task.

When comparing two dependent samples we can state that they considerably differ in the mean value. The average of points was 0.5 points in the first exam and 2 points in the second

exam, that represents the difference of 1.5 points, see table 2. From the overall number of 197 students, 121 did not get any points and 61 got 0.5 or 1 point in the first exam. There were only three students who reached 3 points. In the second exam, in comparison with the first exam, the situation got better. Only 50 students did not get any points. 66 students reached 3 points and more. (Each exam item represents one point in the student test evaluation.)

Variable	N valid	Mean	Min	Max	Standard deviation
Classical calc.	197	0.467005	0.00	3.000000	0.673990
Module usage	197	2.086294	0.00	6.000000	1.848238

Table 2: Descriptive statistics

A graphical representation shows the considerable differences between examined groups of exam results, see figure 1. The vertical axis scale indicates how many points a student obtained (how many of items s/he answered correctly). The difference is seen in the value of the average and in the variability of both samples as well.

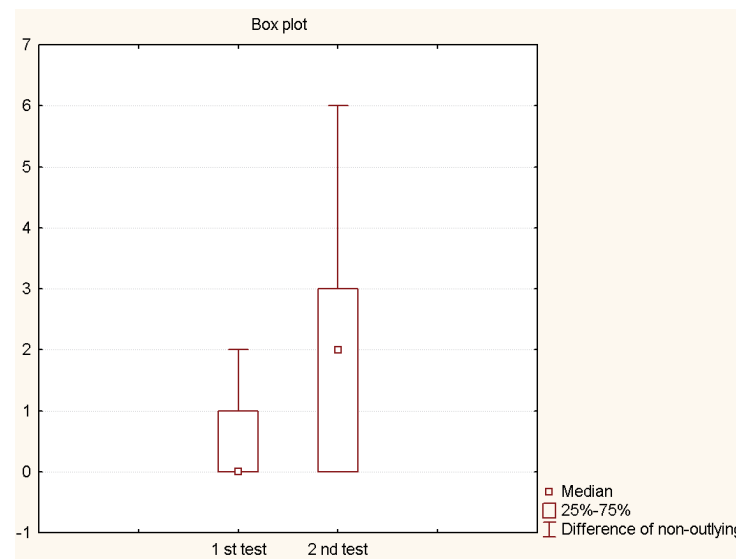


Figure 1: Box plot for comparing the sets of test results (output from STATISTICA 8)

At the beginning of every testing it is necessary to state the hypothesis which we want to test. In this case it was defined in the following way: There is not any statistically important difference between the means of results of the first and the second test. Accepting/rejecting this hypothesis no/a significant impact of the LINKOSA usage would be proven.

In a table form of results there is evaluated statistical importance of differences between the means of dependent samples by means of the paired t-test. The calculated mean difference \bar{d} = -1.619 and standard deviation $s_{\bar{d}}$ = 1.894 correspond to the

value of the test criterion $t = -11.997$. The value p ($p=0.000001$) is smaller than a given significance level $\alpha = 0.05$, that is why we reject a null hypothesis about a statistical unimportance of the difference between the means of dependent samples. Therefore, the impact of the LINKOSA usage is significant.

t-test for dependent samples <i>Italic differences are significant on the level. $p < 0.05$</i>								
Variable	Mean	Standard dev.	N	Difference	Standard dev.	t	df	p
Classical calculat.	0.467	0.674						
Module usage	2.086	1.848	197	-1.620	1.895	-11.997	196	0.0

Table 3: Output of the calculation – pair t-test

For the analysis of qualitative data according to a contingency table, we transferred the point evaluation only to the possibility of passing the exam (three points and more) and failing (two and fewer points). Such a criterion would represent a low demand for students' knowledge. However, we chose it for the purpose of stricter testing of the impact of SW modules usage in classes. A two-dimensional table (see table 3) was tested by means of McNemar test for dependent symbols ($p=0.00000$). The value of χ^2 was 61.016 and C_p was 0.173. The test shown the differences between (non)usage of SW module and the result of the test.

Classical calculation	Module usage		Total
	yes	no	
yes	3	0	3
no	63	131	194
Total	66	131	197

Table 4: Contingency table – module usage x classical calculation

For the item analysis of how good the student is, we used the results of the first part of a credit test which was written in the middle of the term. At the time of results processing into this paper it was the only one proper overall characteristics of the students that was already available. We did not differ among single test variants, i. e. we considered the questions in single variants to be the same questions. The analysis included 5 items for every realization of the test from the both realizations (i. e. 10 items). The first three items are the first three questions stated in the part of Material and Methods, i. e. the questions about the change of an optimum variable value when changing the value of the right-hand side (CV), the change of an optimum value of the objective function when changing the value of the right-hand side (COF), and the limit of the stability interval of the right-hand side (LSI). Remaining three items that students must fill in when answering the fourth question concerning the entering of a non-base variable into the base (EVB), are aggregated into the fourth item. As the last item we evaluate the overall result of the student during the test (OR).

The sample for the item analysis involved only 191 students because 6 students did not participate in the above mentioned credit test (for instance due to their illness or because of other serious reasons).

We summarize the item analysis results in the table 5 (using the abbreviations given above).

Classical calculation					
	CV	COF	LSI	EVB	OR
Facility	11.78%	15.45%	0.52%	6.28%	7.77%
DI	0.092	0.075	0.015	0.032	0.046
DC	0.133	0.116	0.137	0.039	0.162

Module usage					
	CV	COF	LSI	EVB	OR
Facility	32.98%	56.54%	12.74%	13.79%	35.08%
DI	0.149	0.350	0.080	0.059	0.182
DC	0.160	0.330	0.231	0.173	0.294

Table 5: Item analysis results

Found out facility of single questions in the case when students could use only classical calculation corresponds to the fact of how difficult single questions are usually considered. Clearly the most difficult is the LSI determination. The difficulty of this question was strengthened by the fact that the question was asked on a factual, economic level, not downright explicitly in the terms of the operations research and the linear programming theory. In another case of relatively low facility of the question for EVB determination, a negative role is played by a considerable numerical demandness of the calculation.

When using LINKOSA module, the facility of the test considerably increased. With the questions for CV and COF it was roughly three times. The most considerable increase was with the LSI determination that was probably caused by the fact that the stability intervals are calculated by LINKOSA directly and that is why the student did not have to realize additional model calculations with adjusted data. Moreover,

when looking into the LINKOSA results s/he could comprehend that even despite the above mentioned factual character of the question formulation the answer could be found directly in them. On the contrary, the fact that with the question for the EVB determination the facility increased relatively less could be caused by the fact that there was not explicitly given the value of the profit for which it should increase. If the student wanted to use LINKOSA, first of all s/he had to realize that this value must exceed the LSI of the cost coefficient, then select such a value higher than the LSI of the cost coefficient, and only then make the calculation. As it was shown, the students quite often failed in this sequence of steps. However, even despite this, LINKOSA made it easier for the students to solve this question more than twice.

DIs and DCs were all positive. This means that among the items there is not any that would be easier for worse students and more difficult for better ones. From this point of view, the choice of questions for the test was proper (they do not confuse good students etc.) When looking into the results we are attracted by the fact that the DIs and DCs are with all the items considerably higher while using LINKOSA than with the classical calculation. It implies quite an interesting finding that LINKOSA helped particularly good students when solving all the questions. Owing to the fact that in the analyzed sample the correlations are significant on the level of $\alpha = 0.05$ if they are bigger than approximately 0.15, low values of DC, which are actually correlation coefficients, show that in the case of classical calculation the results of single students when solving individual questions practically do not depend on the fact whether the student was good. A certain dependence was shown at the overall result of the test. On the contrary, when using LINKOSA the DCs reveal the dependence of achieved

results on the fact how good the student is, also with single questions.

If we return to the DCs of single items of the test with the classical calculation, the DC of the question to determine EVB is shown as considerably lower than others. It probably testifies its above mentioned numerical demandness because numerical mistakes are made by all the students regardless of how talented they are from the point of view of the professional side of the subject. When using the LINKOSA module for the calculation, the biggest dependence of achieved results on the quality of the student is shown whilst determining COF. LSI determination has also somewhat higher DC which will be probably caused by the factual formulation of this question.

If we focus on the DI values with single items, we will surely notice that there are bigger differences among them than in the case of the DCs. It is caused by the fact that DIs are influenced by the facility of the questions (with questions of low facility more frequent bad answers of good students lower their DI). From this point of view the DIs in general correspond with single items to their facility and DC.

Finally, let us mention another interesting point that resulted from the DI calculation and shows how big contribution LINKOSA represents for the students. The third of the worst students (according to the credit test, examined for the purpose of the DI calculation) on average reached better results using LINKOSA than the third of the best students (according to the same criterion) with the classical calculation. If we look for how many students reached the overall result of the test with a classical calculation at least the same that was the average of overall results of the above mentioned worst third using LINKOSA, we will find out that there were only 15 of such students, i. e. less than 8%.

Conclusion

The results definitely confirmed the assumption about a positive impact of software LINKOSA module usage. According to the results of the item analysis, LINKOSA helps particularly those students who are more talented and more successful for the operations research study. At the same time it helped them when solving all followed fields and topics of linear programming.

Most of all, it will help the students with such data where LINKOSA provided them with the required answer directly in the results, while the classical calculation without its utilisation is relatively difficult. Thus students need not waste their time on a technical side of the calculation while trying hard to comprehend and understand it. In these cases LINKOSA can also serve for results (not procedures) checking while practicing hand calculation. A clearly organized spreadsheet form, which is provided by MS-Excel also enables to comprehend what these data mean as far as the matter-of-fact side is concerned. If the question is set in this way, the students know where to look for the required information in the results.

LINKOSA also helps the students when studying and comprehending the dependence of the change of the solution on the change of a certain parameter (as it was shown for instance with the question concerning the entering of a non-base variable into the base). A lot of patience is required from the students when experimenting with the model, successive changing of a given parameter and examining its influence on the final solution. For this they are rewarded by finding out and comprehending when there occur just quantitative changes, which do not represent the change of the solution structure, and on the contrary, when there occur the changes that can be considered important and qualitative.

In general, LINKOSA enables and deepens the understanding of linear programming of the students. Acquired knowledge can be used by the students in their future practice. Moreover, after the experience with LINKOSA it will be easier for them to work with the professional software.

A similar impact can be expected with other modules owing to their nearly equal user environment and similar way of usage in practice. The exact evaluation of a newly prepared module impact will be possible after its implementation into the classes.

Modules created in the DSE environment cannot be considered to be the substitute of professionally developed software packages. They cannot substitute SW used in a firm or public and administrative environment within the preparation for real problems and within the preparation of real experts in advanced courses. However, they enable the chart demonstration of results and procedures of single methods and in this way they have a considerable importance for the performance, results and knowledge of students.

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